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MORPHOLOGY AND TAXONOMY OF THE CYSTOID *CHEIROCRINUS ANATIFORMIS* (HALL)

BY

ROBERT V. KESLING

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1. Morphology and Taxonomy of the Cystoid *Cheirocrinus anatiformis* (Hall), by Robert V. Kesling. Pages 1–21, with 4 plates.

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CONTENTS

Introduction 1
Localities 3
Systematic descriptions 4
Syntypes AMNH 658/1 4
AMNH 659/1 5
Revised description 5
Remarks 12
Illustrated specimens 15
Literature cited 15
Plates ..... (*after*) 17

INTRODUCTION

FOR THE FIRST TIME, most thecal plates of *Cheirocrinus anatiformis* (Hall) are described. Although the species has been known for over a century, numerous ambiguities remained. To clarify the nature of this cystoid, type specimens were examined, a nearly complete specimen from Michigan was removed from matrix, and additional collections of thecal plates were made in the Northern Peninsula of Michigan. The new study of *Cheirocrinus anatiformis* permits its synonymy to be established. As a result, the species is confirmed to be a widespread index of Trenton rocks in New York, Ontario, and Michigan.

The taxonomy of this cystoid evolved from sporadic reports and was never subjected to thorough revision. In 1847, James Hall, the author of the species, described it as *Echino-encrinites anatiformis*. His illustrations were generalized and his description markedly inadequate. As a result, subsequent authors failed to recognize the species. In 1857, Elkanah Billings described it as his new species *Glyptocystites logani*, and in the following year identified an elongate specimen as a new variety, *G. logani* var. *gracilis*. Hall's *anatiformis* was placed in *Glyptocystites* by Miller (1889) and in *Homocystites* by Whitfield (1898). The latter author seems to have suspected synonymy, for he also listed (1898) "*Homocystites anatiformis* var. *logani*." In 1899, Jaekel put both *anatiformis* and *logani* in "*Chirocrinus*" [*sic*]. Except for the lapse of Springer (1911),

who called it *Glyptocystis logani,* the cystoid was subsequently referred to as *Cheirocrinus anatiformis* (Hall) and *C. logani* (Billings).

One specimen which yielded valuable data was found by Professor Russell C. Hussey (now Professor Emeritus) many years ago, but was never illustrated. Only the antanal side was exposed, and the thecal plates in that area were badly weathered. By prolonged work with Vibrotool and small chisels, I succeeded in removing the dense, finegrained limestone matrix from the other sides of the theca. Because the hardness of the matrix greatly exceeded that of the thecal plates, fine details of ornamentation were destroyed and some parts of plates disintegrated in the course of the preparation. Major ridges and pore rhombs, however, were recovered in such condition that they could be studied in their original association. Photographs of this important specimen are shown in Plates I and II.

To learn more about the ornamentation of plates, I examined isolated thecal plates from various localities in the Northern Peninsula of Michigan. Some rocks bearing plates were available in the collections of the Museum of Paleontology at The University of Michigan. In 1958, I had collected several slabs bearing *Cheirocrinus* plates in the Pine Ridge quarry, west of Escanaba, while on a Museum of Paleontology expedition with Professor G. M. Ehlers (now Professor Emeritus). In May of 1962, with my students in Geology 429, Field Studies in Geology, The University of Michigan, I gathered several more fossiliferous slabs from the Bichler quarry and from outcrops and dredgings along a small stream near the town of Rapid River, Michigan. Several selected thecal plates are illustrated in this paper.

Then I borrowed the type specimens still extant from the American Museum of Natural History. Through the courtesy of Dr. Norman D. Newell, I obtained a loan of four syntypes and an excellent specimen catalogued as AMNH 659/1 *Cheirocrinus logani* (Billings). The latter is shown in Plates III and IV.

A significant contribution from this investigation is the discovery that many isolated plates can be identified not only as belonging to *Cheirocrinus anatiformis* but also as particular plates of the theca. Most cystoids of this species became disarticulated before burial, and occur as isolated thecal plates. These plates, however, have distinctive shape, ornamentation, and pore rhombs. For example, it is also the only described species of the genus in which the *L1/L2* rhomb is a demirhomb on the aboral part of the suture. Further, it is a unique *Cheirocrinus* in lacking a *B2/IL1* rhomb. Of the radials, only *R2* bears two half-rhombs. The *L5/R1a* rhomb is steeply inclined. Major ridges radiate from near the centers of *BB, ILL, LL,* and *RR* to all sides not bearing a full half-rhomb, there joining with

ridges from adjacent plates to form a distinctive network. Within the sectors bounded by major ridges, concentric finer ridges are set normal to the plate sutures. Five plates have rimmed indentations for the periproct. *IL2* has a larger half-rhomb associated with a half-demirhomb than that in any other species. Hence, except for *B1* and *B3,* which are very similar, a complete plate can be readily identified to its thecal location; and, if well-preserved, *B3* can be distinguished from *B1* by its weaker ornamentation in the right sector.

My sincere appreciation to the people who have helped me. Dr. N. D. Newell sent the specimens on loan from the American Museum of Natural History. Dr. Lewis B. Kellum and Dr. C. A. Arnold critically read the manuscript. Mr. Karoly Kutasi assisted with the photography. Mrs. Helen Mysyk did the typing.

Specimens designated AMNH are in the collection of the American Museum of Natural History. Those labeled UMMP are catalogued and deposited in the Museum of Paleontology of The University of Michigan.

LOCALITIES

All Michigan specimens described and illustrated herein are from Middle Ordovician Trenton rocks exposed in Delta County in the Northern Peninsula.

LOCALITY

1. Rock exposed in the bed of the Tacoosh River and slabs brought up by digging or dredging, about ¼ mile north of U. S. Highway 2 along U. S. Highway 41, near the town of Rapid River, SE¼ sec. 19, T41N, R21W. Collected by the author and students, May 1962.

2. Upper 15 feet of strata exposed in the abandoned Bichler quarry, near the village of Groos, about 4 miles north-northwest of Escanaba, SW¼ sec. 1, T39N, R23W. Hussey's "Location 10" (1936, p. 248). Collected by the author and students, May 1962.

3. Rocks exposed in the small Pine Ridge quarry, intermittently operated for road material by the Delta County Highway Commission, north of U. S. Highway 2 and the Chicago & Northwestern Railway, about 4 miles west of Escanaba, SE¼ NW¼ sec. 28, T39N, R23W. Collected by G. M. Ehlers and the author in 1958.

4. "Escanaba River." Collected by R. C. Hussey many years ago, presumably in 1926. Probably, this is "Location 12," described by Hussey (1936, p. 251) as: "About ¼ mile northeast of the Groos quarry, in Delta County, a little island stands in the middle of the Escanaba River. The rock is exposed all around the sides of the island . . . ." He correlated the strata at this locality with those in the Bichler quarry at Groos.

SYSTEMATIC DESCRIPTIONS

Order RHOMBIFERA Zittel, 1879

Superfamily Glyptocystitida Bather, 1900

Family Cheirocrinidae Jaekel, 1899

Genus *Cheirocrinus* Eichwald, 1856

Cheirocrinus anatiformis (Hall)

(Figs. 1–4; Pl. I, Figs. 1–7; Pl. II, Figs. 1–7; Pl. III, Figs. 1–5; Pl. IV, Figs. 1–9)

Echino-encrinites anatiformis Hall, 1847, p. 89–90, Pl. 29, Figs. 4a–f.
Glyptocystites logani Billings, 1857, p. 282–83; 1858, pp. 57–59, Pl. 4, Figs. 1a–1j. Chapman, 1861, p. 514, Fig. 179; 1863, p. 198, Fig. 179; 1864b, p. 170, Fig. 179. Grabau and Shimer, 1910, p. 464.
Glyptocystites logani var. *gracilis* Billings, 1858, p. 59, Pl. 4, Fig. 2.
Echino-encrinites anatinaformis [*sic*] Billings, 1858, p. 58.
Glyptocystites anatiformis Miller, 1889, p. 269.
Homocystites anatiformis Whitfield, 1898, p. 26.
Homocystites anatiformis var. *logani* Whitfield, 1898, p. 26.
Chirocrinus anatiformis Jaekel, 1899, p. 221.
Chirocrinus logani Jaekel, 1899, p. 220.
Glyptocystis logani Springer, 1911, p. 45.
Cheirocrinus logani Bather, 1913, p. 441. Bassler, 1915, p. 213. Bassler and Moodey, 1943, p. 143.
Cheirocrinus logani var. *gracilis* Bather, 1913, p. 442.
Cheirocrinus anatiformis Bassler, 1915, p. 212. Clark, 1919, pp. 10–11, Pl. 1, Fig. 18. Bassler and Moodey, 1943, p. 142. Hussey, 1952, p. 34.
Cheirocrinus logani gracilis Bassler, 1915, p. 213. Bassler and Moodey, 1943, p. 143.
Cheirocrinus sp. Hussey, 1950, p. 13; 1952, p. 35.
Cheirocrinus plates, Hussey, 1952, p. 36.

Syntypes AMNH 658/1.—Of Hall's original specimens, I located four syntypes in the American Museum of Natural History and studied them through the kindness of Dr. N. D. Newell. All are catalogued under the same number.

The largest specimen is a slab bearing the specimens illustrated by Hall (1847, Pl. 29) as Figures 1–3. The cystoids are two crushed thecae with distorted plates and long but incomplete columns. They are considerably smaller than most other known thecae.

A second specimen was shown by Hall as Fig. 4d. This theca and part of the attached column are much better preserved than one might suspect from the original drawing. Although the theca is crushed with *R1a* pressed against *R3* on the opposite side, all plates of the *BB, ILL, LL,* and *RR* series are present. When submersed in liquid, nearly all sutures and rhombs are discernible. The side shown in Hall's figure has the periproct at the left and shows plates *B3, IL2, IL3, L3, R2, R3,* most of *R4,* the right edge of *IL4,* and parts of *B2, B4, L2,* and *L4;* it also con-

tains rhombs *B2/IL2, IL1/IL2, L3/L4, R2/R3,* and parts of *R1b/R2* and *R4/R5*. The specimen is drastically different from the drawing. It shows all the major features that can be found in UMMP 45020 and AMNH 659/1, and appears to be conspecific with them.

The third specimen, originally illustrated by Hall in his Figure 4d′, consists of the aboral part of the theca and some attached columnals. The aspect shown in the figure contains *B1, IL5,* and parts of *B4, IL4,* and *IL1*.

The fourth specimen, designated "h," was not illustrated by Hall. It is a fragment of the theca.

AMNH 659/1.—A remarkably complete theca at the American Museum of Natural History was never described. This is curious, because it is the best specimen in existence, to my knowledge. Not only are all *BB, ILL, LL,* and *RR* plates present, but the specimen also includes a long section of the column, two exposed orals, some ambulacra, and several segments of brachioles.

According to the label accompanying the cystoid, it is from the Curdsville Limestone at Brighton, Ontario. It is called *Cheirocrinus logani* (Billings), and the label has an entry "A. Woodward," signifying, I presume, the collector. At any rate, this specimen was known in 1898, when Whitfield listed it as "*Homocystites anatiformis* var. *logani*" in his catalogue of specimens in the American Museum of Natural History.

Only one side, that centered on *R1b,* shows good rendition of ornamentation (Pl. III, Fig. 5). This side, I believe, was exposed when the specimen was found. Subsequent cleaning of the rest of the theca exposed the rest of the thecal plates except three of the orals. In cleaning, I suspect, some of the major ridges on *B4, IL4,* and *L4* were destroyed (compare Pl. III, Fig. 2, with Pl. I, Fig. 4, and Pl. II, Fig. 2; also compare Pl. III, Fig. 3, with Pl. I, Fig. 3). This was probably unavoidable, inasmuch as the matrix seems to be a very dense, hard limestone. At some time, also, the upper part of the theca was broken into three parts and reassembled (Pl. III, Figs. 1–5).

This specimen is further exceptional for retaining brachioles in place. From it, one can surmise rather well the original appearance of the cystoid.

Revised description.—The following observations are based primarily on UMMP 45020 and AMNH 659/1, supplemented with four syntypes (AMNH 658/1) and numerous isolated plates (UMMP 45021–45031 and uncatalogued specimens).

Shape: Theca more or less urn-shaped, sharply truncated adorally by the nearly flat, gently domed, lidlike layer of oral plates (Pl. III, Figs. 1–2). Aboral part subovoid, with central aboral margins of *BB* and centers

of *ILL* forming protuberances (Pl. I, Figs. 1–7; Pl. II, Figs. 1–2; Pl. III, Figs. 1–5; Pl. IV, Fig. 2). Greatest diameter not more than one-third the length above the column (Pl. I, Fig. 6; Pl. II, Fig. 1; Pl. III, Figs. 1, 3–4). UMMP 45020 somewhat compressed in the anal-antanal direction (Pl. I, Fig. 7) as compared with AMNH 659/1 (Pl. III, Fig. 5), possibly the result of distortion in preservation. Periproct large (Fig. 4*a*; Pl. I, Fig. 3; Pl. II, Fig. 1; Pl. III, Fig. 3), as in other species of the genus. Orals forming a slightly arched subhexagonal roof on the theca; apices of the subhexagon strongly protuberant (Fig. 3) and set atop corresponding ridgelike folds of the radials (Fig. 4*a–c*; Pl. II, Figs. 1–2; Pl. III, Figs. 1–5; Pl. IV, Fig. 1).

Thecal plates: Each tier of plates—*BB, ILL, LL, RR,* and *OO*—forming a closed circlet, although in AMNH 659/1 plates *L1* and *L2* appear to have met only at a point. Four *BB* around the base and adjoining the column (Pl. IV, Fig. 2). *B1* and *B3* subpentagonal, each with ridges extending from the middle of the aboral margin to adjacent *BB* and

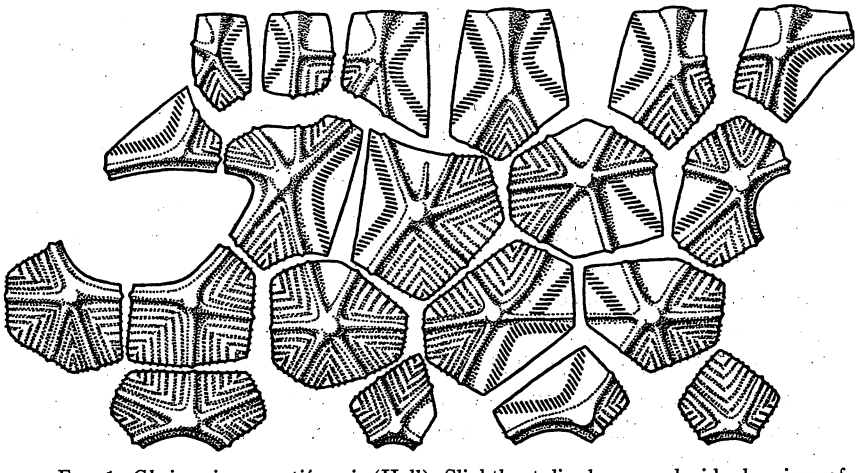

FIG. 1. *Cheirocrinus anatiformis* (Hall). Slightly stylized camera lucida drawings of thecal plates. Plate outlines and ridges determined from UMMP 45020 (see Pl. I, Figs. 1–7; Pl. II, Figs. 1–2) and AMNH 659/1 (see Pl. III, Figs. 1–5; Pl. IV, Figs. 1–2); ornamentation added from isolated plates. Fine details of ornamentation not indicated.

ILL and with a strong protuberance at the junction of the four ridges (Fig. 1). *B2* subpentagonal, its left half wider than the right and bearing half of the full rhomb shared with *IL2*; three ridges radiating from the adoral margin, two to adjacent *BB* and one to adjacent *IL1* (Pl. I, Fig. 6; Pl. IV, Fig. 7); AMNH 659/1 also shows a fairly prominent ridge across

the *B2/IL2* rhomb (Pl. III, Fig. 4); when excellently preserved, the ridges to *B3* and *IL1* form a broad flange (Pl. IV, Fig. 7). *B4* broad, subhexagonal, provided with five ridges radiating from the adoral margin, two to adjacent *BB* and three to adjacent *ILL;* upper margin long, in contact with *IL4.*

Five *ILL* encircling the theca (Figs. 1–2). *IL1* subhexagonal, with six ridges radiating from the central protuberance to adjoining *BB, ILL,* and *LL*; adoral left sector containing a half-demirhomb (Pl. III, Fig. 5). *IL2* an extremely distinctive plate, subhexagonal, with five ridges radiating from the central protuberance to *B3, IL1, IL3, L2,* and *L3* (Pl. III, Fig. 4; Pl. IV, Figs. 3, 5, 7, 9); some plates showing an additional ridge across *B2/IL2* rhomb (Pl. III, Fig. 4); half-demirhomb in adoral right sector and half-rhomb along aboral right side, separated by a sharp, narrow ridge (Pl. IV, Fig. 7). *IL3* subhexagonal, its shortest side adjoining *IL2,* with six ridges radiating from central protuberance to two each of *BB, ILL,* and *LL. IL4* and *IL5* forming lower border of the periproct (Pl. I,

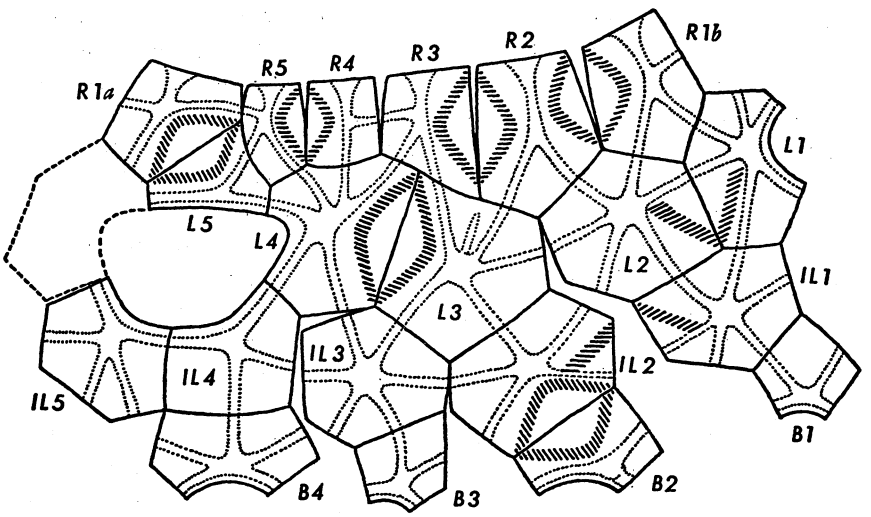

FIG. 2. *Cheirocrinus anatiformis* (Hall). Somewhat stylized plate diagram with conventional symbols. Dotted lines indicate major ridges. Compare with Fig. 1.

Fig. 3; Pl. II, Fig. 1). *IL4* bordered by four plates and periproct, its lower part rectangular and bounded by *B4, IL3,* and *IL5* (Figs. 1–2, 4*a*; Pl. I, Fig. 3); the protuberance situated in the center of the margin next to the periproct, with ridges to *B4* below, *IL3* at the right, *IL5* at the left, and *L4* at the adoral right (Pl. II, Fig. 1). *IL5* bordered by five plates

and periproct; from protuberance in center of margin next to periproct, ridges radiating to *B4, B1, IL4, IL1,* and *L1* (Pl. I, Figs. 2–3).

Five *LL* forming a tenuous ring around the theca, except in AMNH 659/1, which shows *L2* and *L3* originally either meeting at a point or separated by a very short *IL2/R2* suture (Pl. III, Fig. 4). One of the syntypes with definite *L2/L3* suture, and the shape of isolated *IL2* and *R2* plates indicating that *L2* and *L3* probably met along a suture, as indicated in Figure 2. Sutures *L4/L5* and *L1/L5* short (Figs. 2, 4*a*; Pl. I, Figs. 2–4). *L1* bordered by *IL1, IL5, L2, L5,* and two plates representing *R1,* its right side with a deep concavity forming the left edge of the periproct; protuberance in the center of the margin along the periproct, with ridges to each of the six adjacent plates (Figs. 1–2; Pl. I, Fig. 2; Pl. IV, Fig. 5); aboral left sector bearing a half-demirhomb (Pl. IV, Figs. 3, 6, 8). *L2* subhexagonal; ridges radiating from central protuberance to each bordering plate; five or six sides, depending on whether plate has a junction with *L3*; aboral right sector with a half-demirhomb (Pl. III, Fig. 5). *L3* pentagonal (having junction with *L2*) or quadrate (not having junction with *L2*), its long adoral border in contact with *R2* and *R3*; ridges from central protuberance to *L2* in UMMP 45020 (Pl. I, Fig. 6; Pl. II, Fig. 2) but not in AMNH 659/1 (Pl. III, Fig. 4), to *IL2, IL3, R3,* and *R2*; large half-rhomb along left side. *L4* bounded adorally by *R3, R4,* and *R5,* on the right by *L3,* aborally by *IL3,* on the aboral left by *IL4,* and on the adoral left by *L5,* its left side deeply indented to form the right border of the periproct (Pl. I, Fig. 4); protuberance offset to the adoral left, with ridges to each of the surrounding plates except *L3*; large half-rhomb along right side (Pl. I, Fig. 5). *L5* subpentagonal, its long base forming the adoral boundary of the periproct, its short sides by *L4* and *L1,* and its long adoral sides by *R1a* and *R5* (Pl. III, Fig. 3); ridges from center of aboral margin to *L1, L4,* and *R5* (Pl. II, Fig. 1); half-rhomb along adoral left side (Pl. I, Fig. 3).

RR consisting of a circlet of six plates, of which two are interpreted as divisions of *R1* (Fig. 2). Each plate bearing a vertical ridgelike fold attaining maximum development at the adoral border (Pl. II, Fig. 7, lower right of center); this fold a basic structure involving the entire thickness of the plate (Pl. II, Figs. 3–4), not a superficial ornament. Low protuberance on fold near center of each plate, with radiating ridges to adjacent plates except those with which a rhomb is shared. *R1a* subpentagonal, its side adjoining *R5* short, the side adjoining *L1* medium, and those adjoining *L5, R1b,* and the *OO* long; from the protuberance, low ridges to *R5* and *L1* and an obscure ridge to *R1b* (Pl. II, Fig. 1; Pl. III, Figs. 3, 5); half-rhomb in aboral right quadrant (Pl. I, Fig. 3). *R1b* slightly larger

than *R1a,* subpentagonal, nearly symmetrical bilaterally, with ridges from center to *R1a, L1,* and *L2* (Pl. III, Fig. 5); half-rhomb on left side (Pl. I, Fig. 2). *R2* slightly larger than *R1b* but similar in shape, with ridges to *L2* and *L3* diverging aborally from the low central protuberance; half-rhomb on each side (Pl. I, Fig. 1; Pl. II, Figs. 5, 7). *R3* subtrapezoidal with parallel sides, its aboral edge in contact with both *L3* and *L4* (Figs. 2, 4*b*); ridges radiating from center to *R4, L4,* and *L3* (Pl. II, Fig. 2; Pl. III, Figs. 1–2); half-rhomb on right side (Pl. I, Fig. 5). *R4* small, nearly rectangular, slightly higher than wide (Figs. 1, 4*b*), bearing ridges from center to *R3* and *L4* to form a T together with the fold (Pl. III, Fig. 2); left half of plate occupied by a half-rhomb (Pl. I, Fig. 4). *R5* the smallest of the *RR,* more or less five-sided, the short *R1a/R5* suture curved and practically confluent with the longer convex *R5/L5* suture, the *R5/L4* suture short and straight, and the *R5/R4* suture long and straight; three ridges from protuberance to *R1a, L5,* and *L4*; the right side of plate with a half-rhomb (Figs. 2, 4*a*; Pl. I, Fig. 3; Pl. II, Fig. 1).

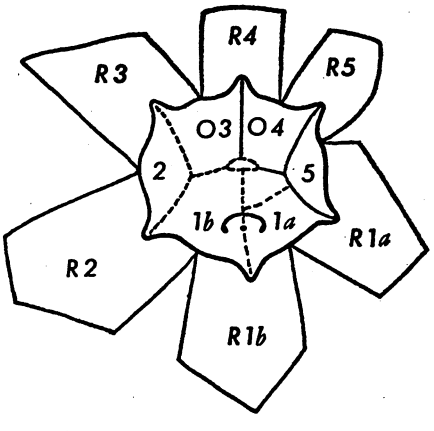

FIG. 3. *Cheirocrinus anatiformis* (Hall). Diagram of oral and radial plates with conventional symbols. Known plate boundaries shown as solid lines and inferred boundaries as dashed lines. Outline of oral plates determined from UMMP 45020 and from oral views of isolated *RR* plates. Plates *O4* and *O5* exposed in AMNH 659/1 (see Pl. IV, Fig. 1). Ambulacral plates and brachiole facets not shown.

OO apparently including six peripheral plates, of which two represent O1 (Fig. 3). Insofar as known, sutures between *OO* extending to protuberant apices of oral circlet. Most of *O1, O2,* and *O3* not seen, except as edges in lateral view; *O1a/O1b* suture atop fold of *R1b* (Pl. I, Fig. 2), *O1b/O2* suture atop fold of *R2* (Pl. I, Fig. 6), *O2/O3* suture atop fold of

R3 (Pl. I, Fig. 5), *O3/O4* suture atop fold of *R4* (Pl. I, Fig. 4), *O4/O5* suture atop fold of *R5* (Pl. I, Figs. 3–4), and *O5/O1a* suture atop fold of *R1b*. Sutures associated with *O4* and *O5* (Pl. IV, Fig. 1) indicate "trimerous" symmetry typical of many pelmatozoans; the three sutures separating *O1a, O4,* and *O5* meeting at a point (Fig. 3) and sutures between *O4* and *O1a* and between *O4* and *O3* meeting near the center of the oral circlet, presumably at the mouth. Thus, *O4* subtrapezoidal and *O5* subtriangular.

Pore rhombs: Theca provided with eight rhombs, the fewest of any species of *Cheirocrinus*. Of these, six developed as full rhombs and two as demirhombs. Shape of rhombs accentuated by enclosing frames of concentric ridges, with full rhombs centered in rhombic areas and demirhombs in triangular areas.

Spacing of slits nearly constant for all rhombs and in thecae of all sizes—approximately 9 slits in 5 mm, or 1.8 slits per mm.

B2/IL2 a full rhomb, enclosed by ridges linking the central protuberances on *B2, B3, IL2,* and *IL1* (Figs. 1, 4*c*; Pl. III, Fig. 4). *IL1/IL2* a chevron-shaped demirhomb, its apex near the junction of the suture with *L2* and it aboral ends near the middle of the plates, with the end of the left half separated from the apex of the *IL2* half-rhomb by a narrow ridge (Figs. 2, 4*c*; Pl. III, Figs. 4–5; Pl. IV, Figs. 7, 9), demirhomb lying within a triangle of ridges linking centers of *IL1, IL2,* and *L2*.

L1/L2 a V-shaped demirhomb inside a triangle of ridges connecting centers of *IL1, L1,* and *L2* (Figs. 1–2; Pl. I, Figs. 2, 7; Pl. III, Fig. 5). *L3/L4* a large full rhomb, framed by ridges between centers of *IL3, L3, R3,* and *L4* (Figs. 2, 4*b*; Pl. I, Figs. 4–5).

Each *R* bearing at least one half-rhomb. *L5/R1a* a full rhomb set diagonally, centered within a rhomb of ridges linking *L1, L5, R5,* and *R1a* (Figs. 1, 2, 4*a*; Pl. I, Fig. 3; Pl. II, Fig. 1). All other rhombs of *RR* framed by incomplete rhombs of ridges, due to absence of ridges extending onto *OO*. *R1b/R2* (Pl. III, Fig. 5) and *R2/R3* (Pl. I, Fig. 1) large, *R4/R5* (Pl. I, Fig. 4) considerably smaller; all three rhombs set vertical (Figs. 2, *4b–c*).

Ornamentation: The following areas bearing concentric triangles of small ridges: *B1–B2–IL1* (Pl. III, Fig. 5), *B1–B4–IL5, B3–B4–IL3, B1–IL1–IL5, B3–IL2–IL3, B4–IL3–IL4* (Pl. I, Fig. 4), *B4–IL4–IL5, IL1–IL5–L1* (Pl. I, Fig. 2), *IL2–IL3–L3, IL3–IL4–L4* (Pl. I, Fig. 4), *L1–L2–R1b* (Pl. III, Fig. 5), *L4–L5–R5, L1–R1a–R1b* (Pl. III, Fig. 5), and *L4–R3–R4* (Pl. I, Fig. 5). In addition to these fourteen triangles, some specimens show *IL2–L2–L3* and *L2–L3–R2,* but AMNH 659/1 appears to have these two triangles fused by the elimination of the *L2/L3* suture, so that the area shows concentric squares of small ridges instead

(Pl. III, Figs. 1, 4); insufficient complete thecae are known to determine if this is an anomaly. The aboral areas between folds of *R1a–R1b* (Pl. I, Fig. 2; Pl. III, Fig. 5), *R3–R4* (Pl. I, Fig. 5; Pl. III, Fig. 2), and *R5–R1a* bearing faint ornament of horizontal ridges.

Areas within rhombs, both full rhombs and demirhombs, crossed by ridges normal to the suture. In some, the ridges distinct and spaced like the slits (Pl. IV, Fig. 7), but in most, the ridges uneven and some more pronounced than others (Pl. IV, Fig. 9).

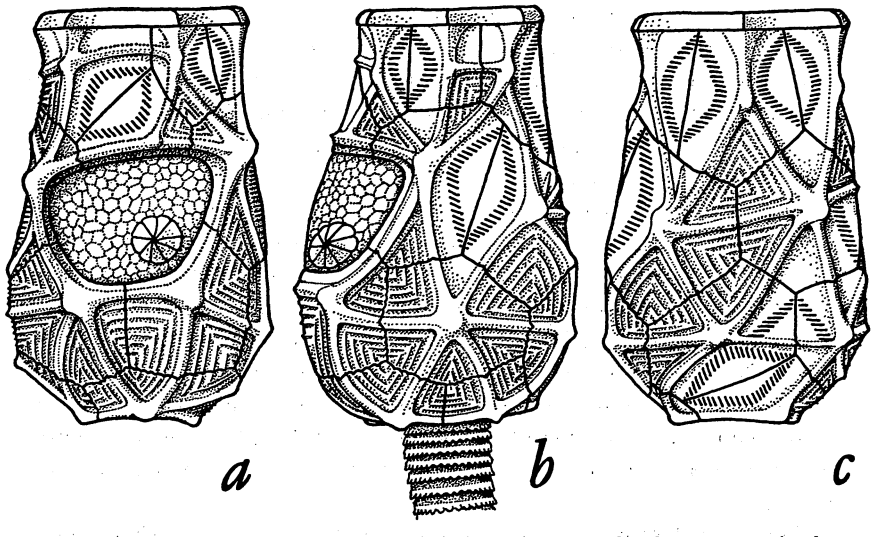

FIG. 4. *Cheirocrinus anatiformis* (Hall). Restorations of the theca as seen in three lateral views, based on UMMP 45020, AMNH 659/1, and various isolated thecal plates. *a,* view centered on periproct (compare with Pl. I, Fig. 3; Pl. II, Fig. 1; Pl. III, Fig. 3); details in periproct hypothetical. *b,* view centered on *R4* (compare with Pl. I, Figs. 4–5; Pl. II, Fig. 2; Pl. III, Fig. 2); theca may be more compressed than shown here. *c,* view centered on *R2* (compare with Pl. I, Figs. 1, 6; Pl. III, Fig. 4). Ambulacra and brachioles atop oral plates not indicated.

Some well-preserved plates displaying growth lines (Pl. II, Figs. 3, 6), emphasized by weathering. Some sectors of plates adjacent to the ends of rhombs ornamented with small papillae instead of ridges (Pl. IV, Fig. 4).

Ambulacra: Covering plates appear to be distributed over and along the sutures separating major *OO* plates; it seems highly likely that there are five ambulacra, as in other cystoids, and that the *O1a/O1b* suture bears the hydropore and gonopore (Fig. 3). In AMNH 659/1, ambulacrum IV, overlying the *O4/O5* suture, provided with a chevron of small

brachiole facets (Pl. III, Fig. 1; Pl. IV, Fig. 1), more or less conforming to the boundary of the protuberance of the *OO* and to the fold of the underlying *R5*. The distribution in this area suggests that the brachiole facets form a pentagram, incomplete in the posterior interambulacrum and somewhat modified by the "trimerous" symmetry of the oral sutures.

Brachioles: From the distribution in AMNH 659/1, brachioles numerous, perhaps as many as forty. Each brachiole long, nearly as long as the theca (Pl. III, Figs. 4–5), narrow, composed of platelets about ½mm long biserially arranged. Along its proximal edges, probably fringing the groove, each brachiole provided with tiny plates (Pl. III, Fig. 5), their position suggesting that they are pinnules, nearly twice as numerous as the platelets to which they attach. Platelets eroded from one brachiole to show the cavity, presumably the food groove, within (Pl. III, Figs. 4–5).

Column: Column conspicuously flared out adorally, insofar as known attaining its greatest diameter at junction with the theca and tapering distally to very small diameter (Pl. III, Fig. 5). Columnals near theca consisting of thin rings, each having an adoral beveled constriction to fit within the next proximal (adoral) columnal, and each bearing small spines around its distal periphery; spines somewhat more irregular in larger specimens (Pl. IV, Fig. 7), but rather evenly spaced in smaller (Pl. IV, Fig. 8). Nature of the junctions and the exceptionally large lumen suggest great original flexibility in this portion of the column. Distal from this section, columnals lack peripheral spines, their length increases slightly, the lumen decreases to a small perforation, and the junctions are flat surfaces.

Periproct: Periproct large, subtrapezoidal, with parallel short aboral and long adoral borders and with sides diverging adorally (Pl. I, Fig. 3; Pl. II, Fig. 1; Pl. III, Fig. 3). Periproct bounded adorally by *L5*, aborally by *IL4* and *IL5*, on the right by *L4*, and on the left by *L1* (Figs. 2, 4*a*). Ridge along margin of periproct, continuous from one plate to the next, bearing a protuberance near the center of its extent on each plate (Pl. I, Fig. 3).

Remarks.—The taxonomic confusion surrounding this species stems from Hall's original description and illustrations. The descriptions compared the species with *Echino-encrinites senckenbergii* von Meyer, which was known from Europe and which bore only slight resemblance to Hall's New York cystoid. It failed to mention any pore rhombs, and only briefly commented on the thecal plates. The figures of the specimens were highly generalized, with many of the lines in the lithographs representing shading rather than ornamentation, as presumed by later workers. In addition, the figures and statements did not agree. Although Hall stated (1847,

p. 89), "Basal or pelvic plates four, three of them pentagonal, and one with the upper angle truncated; second series hexagonal . . . ," his diagram (Pl. 29, Fig. 4*e*) showed two pentagonal and two trapezoidal *BB* and three septagonal and two incomplete *ILL*.

In classifying his Canadian specimens, Billings (1858, p. 58) compared them with "*Echino-encrinites anatinaformis* figured by Professor Hall," evidently a *nomen nullum* for Hall's species. Billings distinguished his specimens from the published information of Hall primarily on the basis of the ornamentation and shape of thecal plates. As pointed out above, these features were inaccurately indicated in Hall's figures. Billings further noted the absence of rhombs in Hall's figures. From a consideration of these differences, Billings decided his cystoids were different, and proposed a new name for them—*Glyptocystites logani.*

Another matter for which I can find no support is the rather curious description of the column given by Billings (1858, p. 58), who wrote:

> The column is short, strongly annulated, and tapering to a point at its lower extremity. The small joints are pentagonal, and present a very remarkable character in the fact, that their angles form five spiral lines round the column throughout its length. The large joints which constitute the annulations of the column appear to be circular; but none of the specimens are sufficiently well-preserved to shew clearly that they are so.

This odd arrangement was not substantiated even by Billings' own figures; in his explanation of Figures *1i* and *1j,* he stated: "Fragments of columns; the specimens are crushed, and do not clearly show the spiral arrangement."

My observations of the column more closely agree with the original description of the species. Hall (1847, p. 89) said:

> Column short; lower extremity very slender, and composed of joints which are twice or thrice as long as broad; in ascending, the diameter increases, and the joints are shorter, finally becoming flat rings with prominent sharp edges, being nearly one half the diameter of the cup above.

The features ascribed to the column by Billings were accorded considerable specific value by some later authors.

Regarding the ambulacra, Billings (1858, pp. 57–58) wrote: ". . . calycinal ambulacral grooves, to the angles of the truncated apex, bordered by marginal plates, as in *G. multiporus,* and furnished near their extremities each with several smaller free arms, or stout pinnulae, articulated in two series . . . ." Clark (1919, p. 11) mentioned "a series of small plates covering the ventral grooves." Unfortunately, neither author illustrated these features or elaborated on the details.

The identity of *Cheirocrinus anatiformis* and *C. logani* can scarcely be questioned. Both lack the *B2/IL1* rhomb that characterizes other known species of the genus; both have the same kinds of rhombs *B2/IL2,*

IL1/IL2, L1/L2, R1b/R2, and *R2/R3*; both have rhomb-bearing plates of the same shape; and they have the same patterns of ornamentation.

Cheirocrinus anatiformis is compared with similar species in Table I. It can be readily separated from *C. radiatus* Jaekel, *C. hyperboreus* Regnéll, and *C. penniger* Eichwald by the absence of rhombs *B2/IL1* and *R1a/R1b*; it further differs from *C. radiatus* in lacking rhombs *IL3/L4, IL4/L4, L2/L3, L3/R3, R1a/R5,* and *R3/R4,* from *C. hyperboreus* in lacking rhombs *B1/B2, IL1/L1, IL1/L2, L1/R1a, L2/L3, L2/R2, L4/R5,* and *R1a/R5,* and from *C. penniger* in lacking rhombs *B1/B2, B2/B3, IL3/L4, IL4/L4, L2/R1b, L3/R2,* and *L5/R5*. Of the three species with which it is compared, *C. anatiformis* most closely resembles *C. radiatus* in having rhombs *IL1/IL2, L1/L2,* and *R4/R5,* rather than *C. hyperboreus* and *C. penniger,* which lack these rhombs.

TABLE I

PORE RHOMBS IN RELATED SPECIES OF *Cheirocrinus*

Rhomb	*C. anatiformis* (Hall)	*C. radiatus* Jaekel	*C. hyperboreus* Regnéll	*C. penniger* Eichwald
B1/B2	–	–	d	d
B2/B3	–	–	–	d
B2/IL1	–	R	R	R
B2/IL2	R	R	R	R
IL1/IL2	d	d	–	–
IL1/L1	–	–	R	–
IL1/L2	–	–	R	–
IL3/L4	–	R	?	R
IL4/L4	–	d	?	d
L1/L2	d	R	–	–
L1/R1a	–	–	R	–
L2/L3	–	R	R	–
L2/R1b	–	–	–	R
L2/R2	–	–	R	–
L3/L4	R	R	?	R
L3/R2	–	–	–	d
L3/R3	–	R	?	R
L4/R5	–	–	R	–
L5/R1a	R	R	R	R
L5/R5	–	–	–	R
R1a/R1b	–	R	R	R
R1a/R5	–	R	R	–
R1b/R2	R	R	?	R
R2/R3	R	R	?	R
R3/R4	–	R	?	–
R4/R5	R	R	–	–

R, full rhomb. d, demirhomb. –, no rhomb. ?, unknown.

The presence of only eight rhombs in *C. anatiformis,* as contrasted with 16 in *C. radiatus,* 15 in *C. penniger,* and 12 or more in *C. hyperboreus,* and the absence of rhomb *B2/IL1* suggest that this species might well be made the type of a new genus. Until additional related species are known, however, I should prefer to retain it in *Cheirocrinus*. The unusual association of half-rhomb and half-demirhomb on plate *IL2* is strikingly similar in *C. anatiformis* and *C. radiatus*.

Illustrated specimens.—UMMP 45020, a nearly complete theca bearing part of the column, Locality 4. UMMP 45021–45024, four slabs bearing plates, Locality 3. UMMP 45025, 45028–45029, and 45031, four slabs bearing plates, Locality 1. UMMP 45026–45027 and 45030, three slabs bearing plates, Locality 2. AMNH 659/1, a nearly complete theca with associated column and some brachioles, Curdsville Limestone, Brighton, Ontario.

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PLATES

EXPLANATION OF PLATE I

(All figures × 2)

Cheirocrinus anatiformis (Hall)

All figures of UMMP 45020. Locality 4.

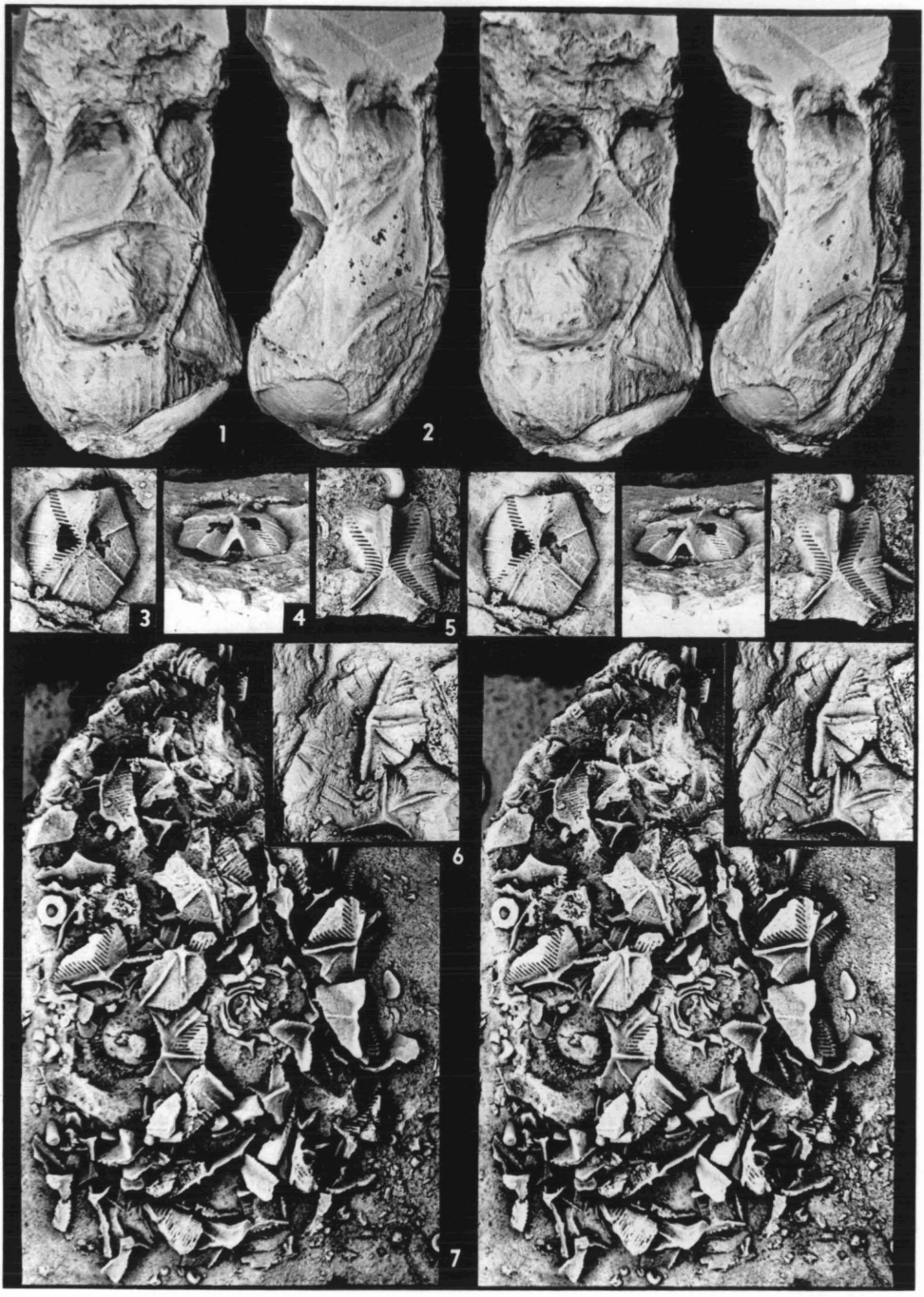
FIGS. 1–5. Lateral views of specimen submersed in xylol. 1, antanal side centered on *R2*; rhombs *R2/R3* and *R1b/R2* are clearly seen in the upper part of the theca, a part of rhomb *L1/L2* at the right, and portions of rhombs *B2/IL2* and *IL1/IL2* in the lower part, where plates are exfoliated; compare with Figure 4*c* in the text and Figure 6 on this plate. 2, side centered on *R1a/R1b* suture; periproct is at the right side; rhomb *L1/L2* is shown near the center, *R1b/R2* at the upper left, and part of *L5/R1a* at the upper right. 3, anal side centered on periproct; rhomb *R4/R5* is at the upper right and *L5/R1a* at the upper left; compare with Figure 4*a* in the text and Plate II, Figure 1. 4, side nearly centered on *R4*; rhomb *R4/R5* at the top, *L5/R1a* at the upper left, and *L3/L4* at the right. 5, side centered on rhomb *L3/L4;* periproct is at the left and rhombs *R2/R3* and *R4/R5* at the upper right and left.

FIG. 6. Stereogram of antanal side of specimen coated with sublimated ammonium chloride. Part of the column shown in position as preserved. Impressions above orals atop rhomb *R2/R3* (upper left) probably represent brachioles. Compare with Figure 4*c* in the text and Figure 1 on this plate.

FIG. 7. Stereogram of side centered on *R1a/R1b* suture of specimen coated with sublimated ammonium chloride. Column removed. Compare with Figure 2 above.

PLATE I

PLATE II



EXPLANATION OF PLATE II

(All figures × 2)

Cheirocrinus anatiformis (Hall)

All specimens coated with sublimated ammonium chloride.

FIG. 1. Stereogram of anal side of UMMP 45020. Compare with Plate I, Figure 3, which shows same view of the theca submersed in xylol. The form of the theca is better expressed by the coating and the pore rhombs by the submersion.

FIG. 2. Stereogram of side of UMMP 45020 centered on rhomb *L3/L4*. Compare with Plate I, Figure 5, which shows same view of theca submersed in xylol. The shape of the rhomb is emphasized by a concentric frame of ridges connecting centers of *IL3, L3, R3,* and *L4*.

FIGS. 3–4. Lateral and oral stereograms of isolated *R1b,* UMMP 45021, showing the strong fold in the adoral half of the plate. Locality 3.

FIG. 5. Lateral stereogram of incomplete isolated *R2,* UMMP 45022. Locality 3.

FIG. 6. Lateral stereogram of isolated *IL3* displaced and partly overlapping *B3,* UMMP 45023. Note fine growth lines on *IL3*. Locality 3.

FIG. 7. Stereogram of jumbled thecal plates, typical of occurrences, UMMP 45024. No two plates retain their original relationship. Identified plates include *B2* (central left), *L1* (lower left of center), *R2* (central right), and *R3,* with exceptionally well-preserved fold (lower right of center). Locality 3.

EXPLANATION OF PLATE III

(All figures × 2)

Cheirocrinus anatiformis (Hall)

All figures of AMNH 659/1, lightly coated with sublimated ammonium chloride.

FIGS. 1–3. Lateral stereograms of theca centered on *R3*, *R4*, and periproct respectively. Upper part of theca was broken into three pieces, presumably during cleaning, and reassembled; the cracks are obvious. The ridges from *L4* to *IL3* and to *R3* were probably destroyed in exposing this part of the theca (compare with UMMP 45020 in Pl. I, Fig. 5).

FIG. 4. Lateral stereogram of theca centered on *R2*, with parts of attached brachioles. In this specimen, plates *IL2*, *L2*, *L3*, and *R2* practically meet at a point (compare with Fig. 4*c* in the text); by contrast, in UMMP 45020, plates *L2* and *L3* apparently joined at a suture, as indicated by a ridge extending to the right from the center of *L3* (Pl. I, Figs. 1, 5, 6; Pl. II, Figs. 2), presumably leading to the center of *L2* across the *L2*/*L3* suture.

FIG. 5. Lateral stereogram of theca centered on *R1b*, with parts of attached brachioles and with column replaced in the original position. This was the weathered surface of the theca, and shows finer details than unexposed parts. Brachioles biserial, bearing tiny platelets along borders of the groove. Rhombs *B2*/*IL2*, *IL1*/*IL2*, *L1*/*L2*, and *R1b*/*R2* clearly shown.

PLATE III

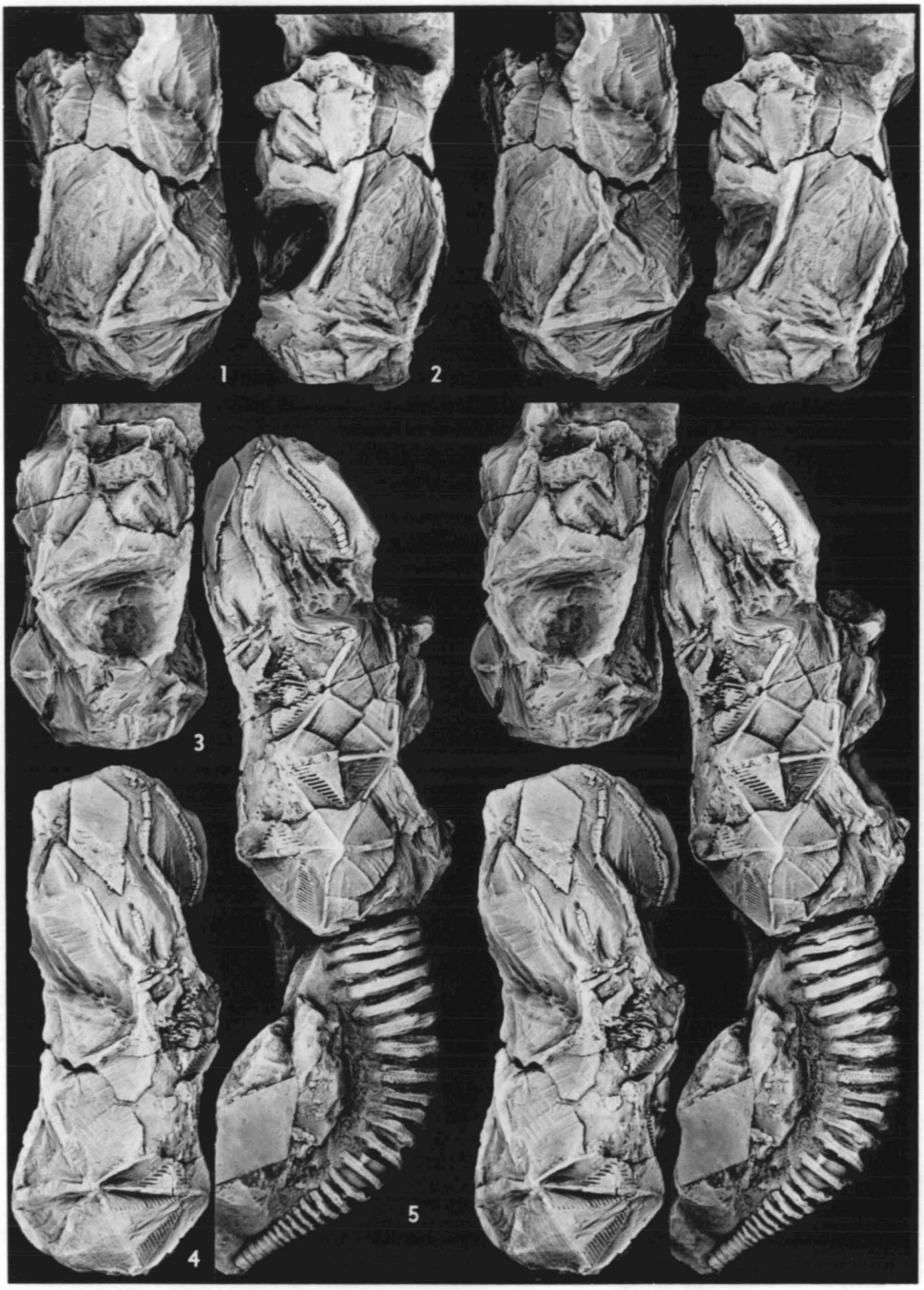
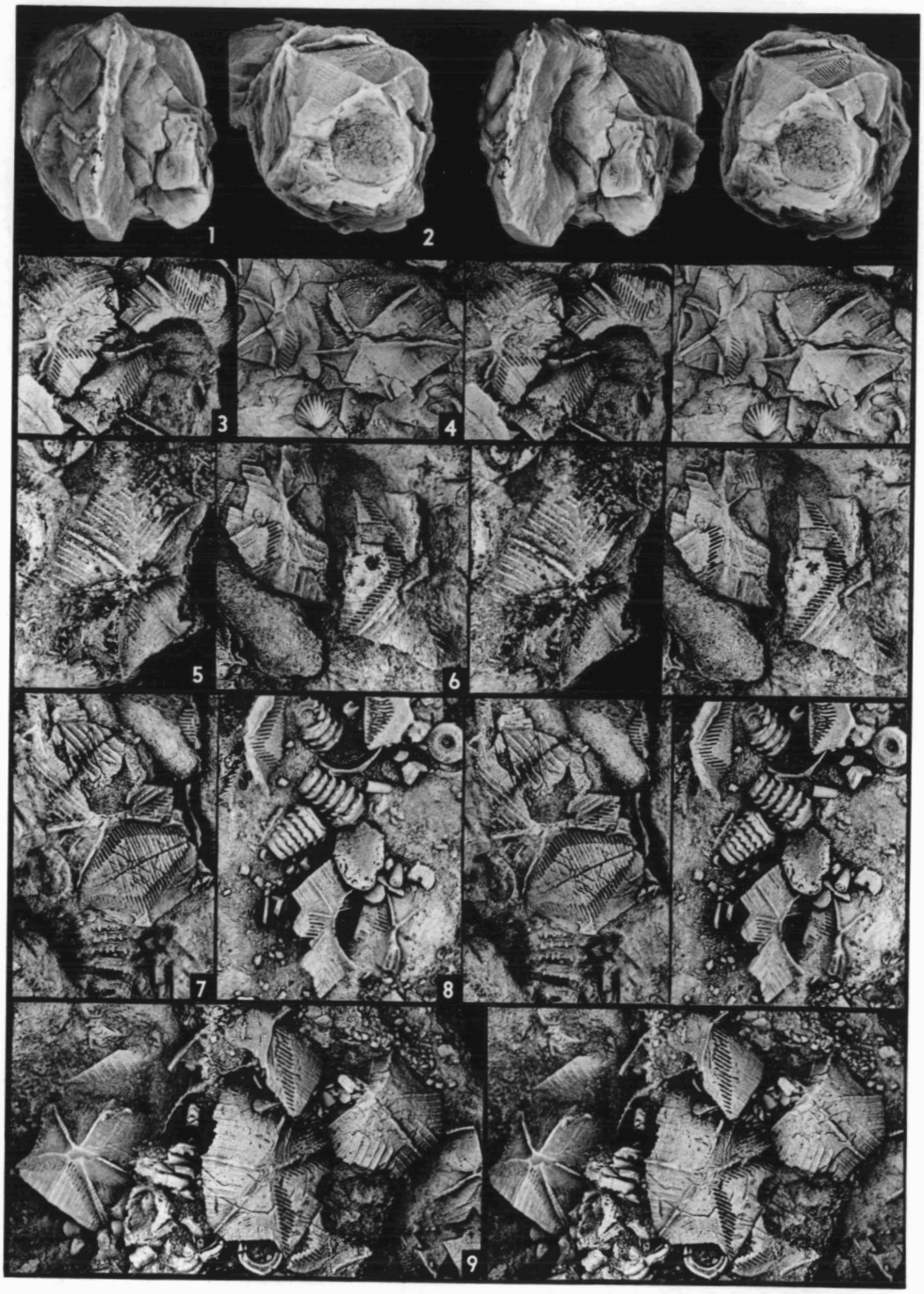


PLATE IV



EXPLANATION OF PLATE IV

(All figures × 2)

Cheirocrinus anatiformis (Hall)

All figures lightly coated with sublimated ammonium chloride.

FIGS. 1–2. Oral and aboral stereograms of AMNH 659/1. Oral view shows brachiole facets forming a chevron on ambulacrum IV (see also Pl. III, Fig. 1). Aboral view has *B2* above the junction with the column.

FIG. 3. Stereogram of UMMP 45025, showing isolated *IL2* (left) and *L1* (right). Locality 1.

FIG. 4. Stereogram of UMMP 45026, showing isolated *IL2* (right). Locality 2.

FIG. 5. Stereogram of UMMP 45027, showing an incomplete exceptionally large *IL2*. Locality 2.

FIG. 6. Stereogram of UMMP 45028, showing isolated *L1* (left) and a radial, probably *R1b* (right). Locality 1.

FIG. 7. Stereogram of UMMP 45029, showing associated section of column, *B2, IL2,* and part of *L3*. Locality 1.

FIG. 8. Stereogram of UMMP 45030, showing three adoral (proximal) sections of small columns, *L1* (below), and interior of a half-rhomb (upper right). Locality 2.

FIG. 9. Stereogram of UMMP 45031, showing isolated *IL2* (left), *?IL5* (right), and associated *IL2* and *B2* (center and lower right). Locality 1.